The Influence of the UV-Intensity on I. F.-Filter Protected Second Surface Mirror α_s Stabilities, Including Surfaces with Conductive Top Layers.

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ABSTRACT

The current MBB experimental research program for satellite thermal household control is directed toward improvement of the satellite thermal life time of passively controlled satellites. To retard the commonly experienced degradation of the solar absorption coefficient of SSM and OSR, several protective thin film coatings have been applied to Teflon FEP SSM and Suprasil glass OSR. Both substrate materials were chosen because of their superior stability under solar radiation exposure, compared to other plastics and glasses. The performance of these protected substrates was evaluated in terms of their α_s changes under accelerated solar radiation test conditions, with 7,5 solar constants (SK), 3,5 SK, and 2 SK. Several sets of samples were exposed to UV radiation only, and to UV and proton radiation simultaneously. A few samples were coated with a thin layer of In_2O_3 to study their surface resistance during the course of simulated solar radiation exposure.

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1.0 INTRODUCTION

Experimental studies point toward the short wave length UV radiation as the cause of SSM and OSR α_s degradation, besides particle radiation.[1,2,3] To protect the SSM and OSR against the influence of the short wave length solar UV radiation, without adding weight, interference filter may be deposited on such surfaces, which either reflect or absorb the detremental part of the UV spectrum of the sun.

Among the materials with sufficiently high stability under solar radiation exposure are ZnS with a high index of refraction, and ThF_4 as well as Al_2O_3, both with a low index of refraction. ZnS alone may be interesting as protective shield, because it strongly absorbs below 3500 Å even as a $\lambda/4$ layer. - Interference filter, fabricated from successive $\lambda/4$ layers of ZnS and ThF_4 or ZnS and Al_2O_3, have shown high stability under simulated solar radiation. Therefore they are candidate materials for IF filter fabrication on SSM and OSR. - In conjunction with static spacecraft surface charging in geostationary orbits, thin conductive In_2O_3 + 10% SnO_2 coats as top layers are of particular importance for undisturbed satellite communications. The conductivity of such films atop of the interference filters also has been tested under simulated solar radiation conditions.

The α_s stability of surface layers may depend on the intensity of the simulated solar radiation. Impressive results, obtained under highly accelerated test conditions may not necessarily repeat under exposure with less intense UV radiation.

To save time, selected samples first were exposed to 7,5 solar constants UV radiation over 3000 ESH and subsequently to 7,5 SK UV and proton radiation, with a total of 10^{16} protons/cm^2, at 10 KeVolt proton energy, again over 3000 ESH.

To study the dependence of α_s changes on the radiation intensities, above tests were repeated under similar conditions, first with 3,5 SK UV exposure, and 30 KeV proton energy, and subsequently with 2 SK and 20 KeVolt proton energy. Each time one set of samples was irradiated with UV alone, and thereafter a second set of identical samples was exposed to UV and protons simultaneously. All tests were extended over 3000 ESH.

It was not possible, to generate proton intensities below 10^{10}/cm^2 sec. For this reason proton irradiation proceeded in intervals during the UV exposure, till 10^{16} protons/cm^2 were brought onto the samples. During proton irradiation the proton beam was not neutralized.

2.0 THE MBB SOLAR RADIATION SIMULATION TEST FACILITY

2.1 The Combined Effects Chamber

The MBB solar radiation simulation test facility consists of five main building blocks, the vacuum chamber with ion pump, the spectrophotometer with digital data reduction equipment for in situ on line α_s determination, the UV source, the proton generator and the electron gun. The UV intensities are adjustable between 7,5 solar constants and 2 solar constants, employing OSRAM XBO 900 W/4 and XBO

450 W/4 Xenon high pressure lamps with Suprasil bulbs. The proton intensities are adjustable between 10^{10} and 10^{11} protons/cm^2 sec; the electron intensities may be selected between 10^{10} and 10^{12} /cm^2 sec. Proton and electron energies range between 5 KeV and 50 KeV.

Both, the proton source and the electron gun were layed out to insure uniform intensity distribution accross the target area, independent of the acceleration potential. Both currents follow the $U^{3/2}$ law. The electron current density can be adjusted through its heater power input. Electron emitter is a L-cathode, which repeatedly may be exposed to air after formation.

The protons are extracted through a 0.6 mm diameter capillary, which takes care of the pressure difference between the RF ion source and the vacuum system. The hydrogen pressure within the RF ion source is around 50 microns. A unipotential lens beneath the capillary insures equal proton current density distribution, independent of the acceleration potential.

Threec Faraday cups can be moved across the sample area, close to the samples, to scan electron and proton current densities. The current density distribution over the samples is affected by the build up of retarding potentials on nonconductive sample surfaces.

During the application of acceleration potentials exceeding 20 KVolt, occasionally discharges around and also through the 5 mil thick samples were observed. Such discharges can damage the plastic foil. In some cases, also the reflector was damaged by discharges, because here the reflector is isolated against ground through a thin layer of glue.

2.2 UV-Calibration of a OSRAM XBO 900 W/4 Light Source

Earlier studies pointed toward the short wave length UV radiation as the major cause of α_s deterioration under solar radiation.[1,2,3] For a better assessment of the UV inflicted damages to the SSM and OSR, efforts therefore were expended for calibration of the UV source, a Xenon high pressure lamp with Suprasil bulb, including all elements within the light beam.

For light projection onto the samples a parabolic mirror was employed. Through a sapphire window the light beam enters the vacuum chamber. Air and water vapor strongly absorb below 1860 Å. For this reason the light source is operated within a heat exchanger, which is filled with spectrally clean nitrogen. Suprasil absorbs between 1700 Å and 1600 Å. Beyond 1600 Å the UV intensities are practically zero.

A new XBO 900 W/4 was calibrated in the spectral range from 1600 Å to 3000 Å with a JOBIN-YVON H - 20 monochromator. Through application of three filters of known transmittance it was possible to eliminate stray radiation in particular below 2500 Å. As secondary standard served a D - 15 Deuterium lamp, which was calibrated at the DESY facility at Hamburg, West Germany. Since absolute calibration at an electron synchrotron is not a simple straight forward task, the calibration curve was fixed to the radiation intensity of a well known tungsten band lamp at 2800 Å. This calibration was accomplished with an integrating sphere, which was installed between light source and monochromator. Because of the short wave length UV under consideration the inside of this integrating sphere was aluminum coated after sandblasting the day before the calibration. All components but the heat exchanger were under vacuum. During the calibration the heat exchanger continously was rinsed with spectrally clean nitrogen.

In Fig. 1 the integrated irradiance from 1600 Å to λ is plotted. For comparison the integrated solar irradiance according to ASTM E 490 is added[4]. The steep increase of the UV intensity between 1600 Å and 1700 Å can be attributed to the transmittance of the Suprasil enveloppe within this wavelength range. In the short wave length range the UV output of the lamp by far exceeds that of the sun. However, with increasing wave length both curves come closer together. At 3000 Å the integral intensity amounts to about 13 solar constants and decreases further to 7,5 solar constants at 4000 Å, in good agreement with radiometer measurements.[5]

In conclusion it should be mentioned, that the UV intensities in the short wave length range exceed those of the sun. The integral intensity of a new XBO 900 W/4, operated at nominal current in this geometry, corresponds to 7,5 solar constants at the samples. With a XBO 450 W/4 intensities between 3,5 SK and 2 SK can be maintained.

2.3 In Situ α_s Evaluation

The sample holder accepts a total of fourty samples. Eight samples may be exposed simultaneously. The sample temperatures can be adjusted between -100° C and $+100^{\circ}$ C. Within

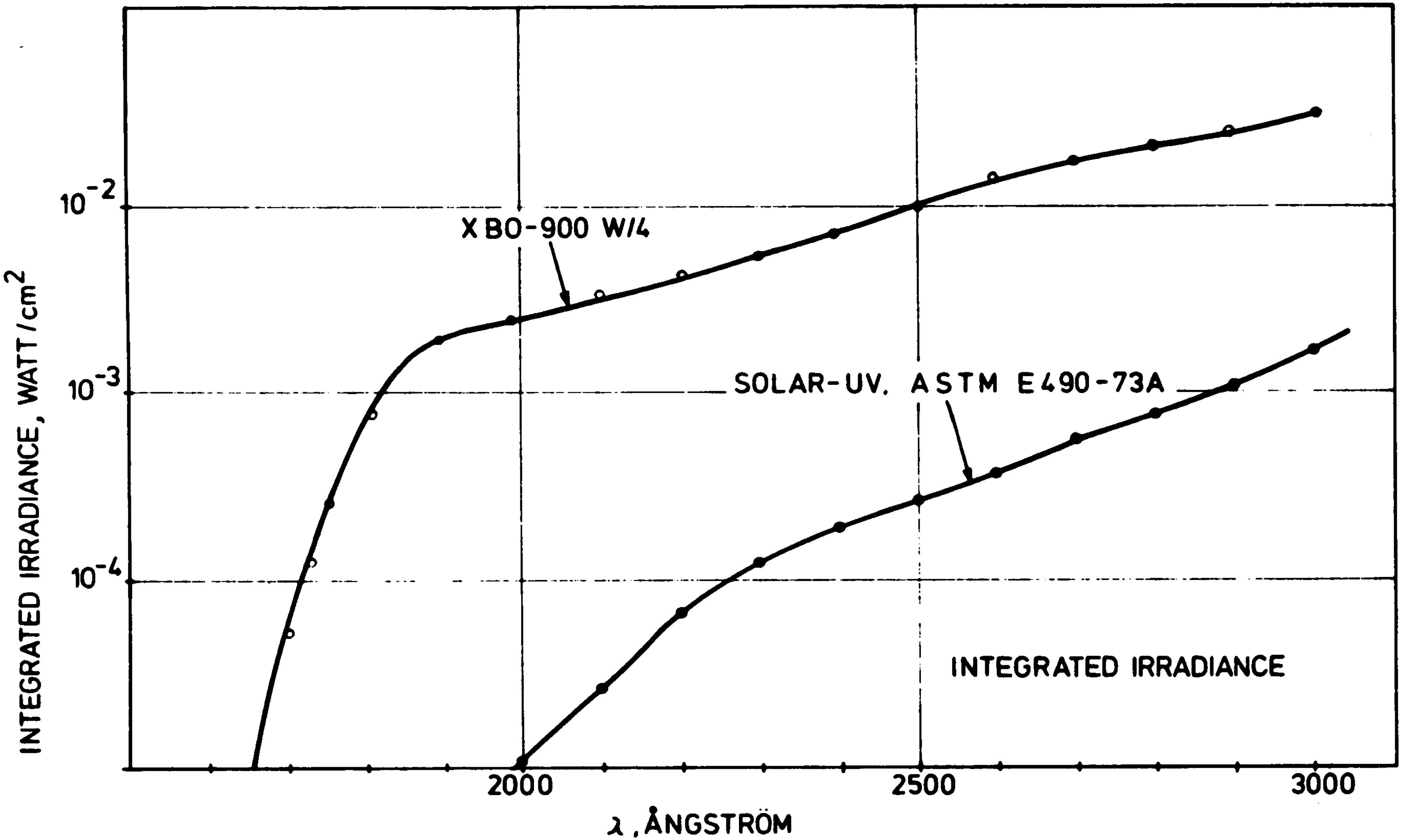

FIGURE 1 INTEGRATED IRRADIANCE FROM 1600 Å to λ, IN WATT/cm^2, OF A NEW XBO 900 W/4. FOR COMPARISON THE INTEGRATED SOLAR UV IRRADIANCE HAS BEEN ADDED.

the vacuum container is an integrating sphere, under which the samples may be turned for in situ measurement of their spectral reflectances. For the α_s evaluation a total of 132 spectral reflectance data in the wave length range from 2400 Å to 2,5 micron are fed into a programmed WANG 600/14 calculator. The solar absorption coefficient is available at the end of the spectral scan.

3.0 PROTECTIVE COATINGS

3.1 Deposition Techniques

The IF filter were fabricated by the R. Bosch company. For IF filter material selection a total of 13 dielectric substances had been vapor deposited on Suprasil as substrate.[6,7] The backside of the Suprasil carrier was coated with an aluminum reflector, about 1500 Å thick. Suprasil was chosen as substrate, because it has shown to be fairly stable under UV exposure. In addition it is nearly free from absorption down to 1700 Å. Therefore changes in the absorption coefficient were caused by changes within the thin film coating material.

Vapor deposition of fluorides followed standard techniques, with the vacuum in the 10^{-6} Torr range. Oxide films were reactively deposited under an oxygen partial pressure of 2×10^{-4} Torr. For the production of SiO_2 films the starting material was the suboxide SiO, for the production of Al_2O_3 coatings, pure aluminum was evaporated. Deposition rates for dielectric materials were between 5 to 10 Å per sec, and for metals between 50 and 100 Å per sec. The deposition rate as well as the thickness of the final layers was monitored and adjusted with a quartz balance, which previously was photometer calibrated with $\lambda/4$ layers.

To insure sufficient adherence of the IF filter to Teflon FEP, at first a thin aluminum layer, about 20 Å thick, is deposited on Teflon. Subsequently, the other compounds, always starting with ZnS, were vapor deposited. The 20 Å thick aluminum layer partly reacts with the fluor of the substrate, partly it reacts with oxygen from the residual gas atmosphere and forms a completely transparent layer, which improves the adherence of the IF filter to the substrate.

The Interference filter are composed of seven alternating layers, each $\lambda/4$ thick, starting with ZnS. ZnS has a high index of refraction. In addition, it efficiently absorbs the UV radiation below 3500 Å, and as top layer eliminates UV exposure below 3500 Å for the subsequent layers, including the Teflon FEP substrate.

The second layer was fabricated either from ThF_4 or AL_2O_3. In conjunction with its radioactivity, ThF_4 was considered less desirable, and more emphasis was placed on the development of highly transparent stoichiometric Al_2O_3 coats. Stoichiometric deposition of Al_2O_3 and SiO_2 layers is difficult. For Al_2O_3 deposition electron beam and reaction deposition techniques were compared, with and without annealing. Finally reaction deposition was selected after several tests, concerning the α_s stability of these coatings.

In conjunction with the strong UV absorption of ZnS below 3500 Å it is of no advantage to place the IF filter reflectance maximum into this region. Either reflection or absorption protect the underlying materials against the UV radiation. If radiation damage is inflicted to transparent materials, such damage may appear as increased absorption in any part or parts of the spectrum, depending on the material. To reduce or to eliminate the consequences of such damage (α_s-increase), e.g. yellow coloration of Teflon FEP, it is of advantage to place the reflection maximum of the IF filter over the spectral range of increased absorption. By application of this technique the light is reflected instead of being absorbed. Therefore the solar absorption coefficient shows less increase, compared to other placings of the IF filter reflection maximum.

3.2 SSM and OSR Transmission

Also the reflector of the SSM can excert some influence on the satellite thermal life time, if the short wave length UV is not absorbed by e. g. a ZnS layer.

Under such condition a silver reflector absorbs below about 3000 Å, in contrast to the high reflectance of aluminum reflectors in this wave length range. With Al-reflectors the UV passes twice through the transparent foil, with the Ag reflector only once.

During the exposure with 3,5 solar constants, a few samples without reflector were incorporated into the test array. These ZnS/Al_2O_3 IF filter on Suprasil were exposed to 3000 ESH UV and also to the same amount of UV simultaneously with protons of 30 KeVolt, to a total of 10^{16} protons/cm^2. One set of these samples consisted of eight layers, starting with Al_2O_3. The second set of samples with seven layers had ZnS on top.

After exposure to simulated solar radiation these samples again were checked for their spectral transmittance in air. Neither the depth nor the wave length of the transmission minimum had changed after exposure. The small differences measured can be attributed to the IF filter fabrication. The good agreement of the transmission curves, measured before and after solar radiation exposure, leads to the conclusion, that the ZnS/Al_2O_3 IF filter now remain unaffected, independent of the top layer material. (Fig. 2) Because of this favorable result, in subsequent tests at two solar constants, a few ZnS/ThF_4 samples were exchanged for ZnS/Al_2O_3 samples.

3.3 Conductive Coatings

The interference filter materials are insulators. Under UV and particle radiation they charge up. If high potentials develop, arc discharges between the satellite structure and these charged surfaces may cause interference with the satellite communications system. An efficient approach to eliminate such charges is the overcoating of thermal surfaces with a thin layer of transparent conductive material, such as In_2O_3.[8,9] This conductive layer must be connected to the satellite structure. The resistance of the conductive coating may be high, because of the low density charged particle streams in outer space, e. g., in a geosynchronous orbit.

For the two solar constant tests reported here, two Teflon FEP samples with ZnS/Al_2O_3 IF filter, conductive coating and Ag reflector were incorporated for exposure to UV + protons, protons, and electrons. Those samples, which were exposed to UV only, instead included two ZnS/ThF_4 IF filter protected

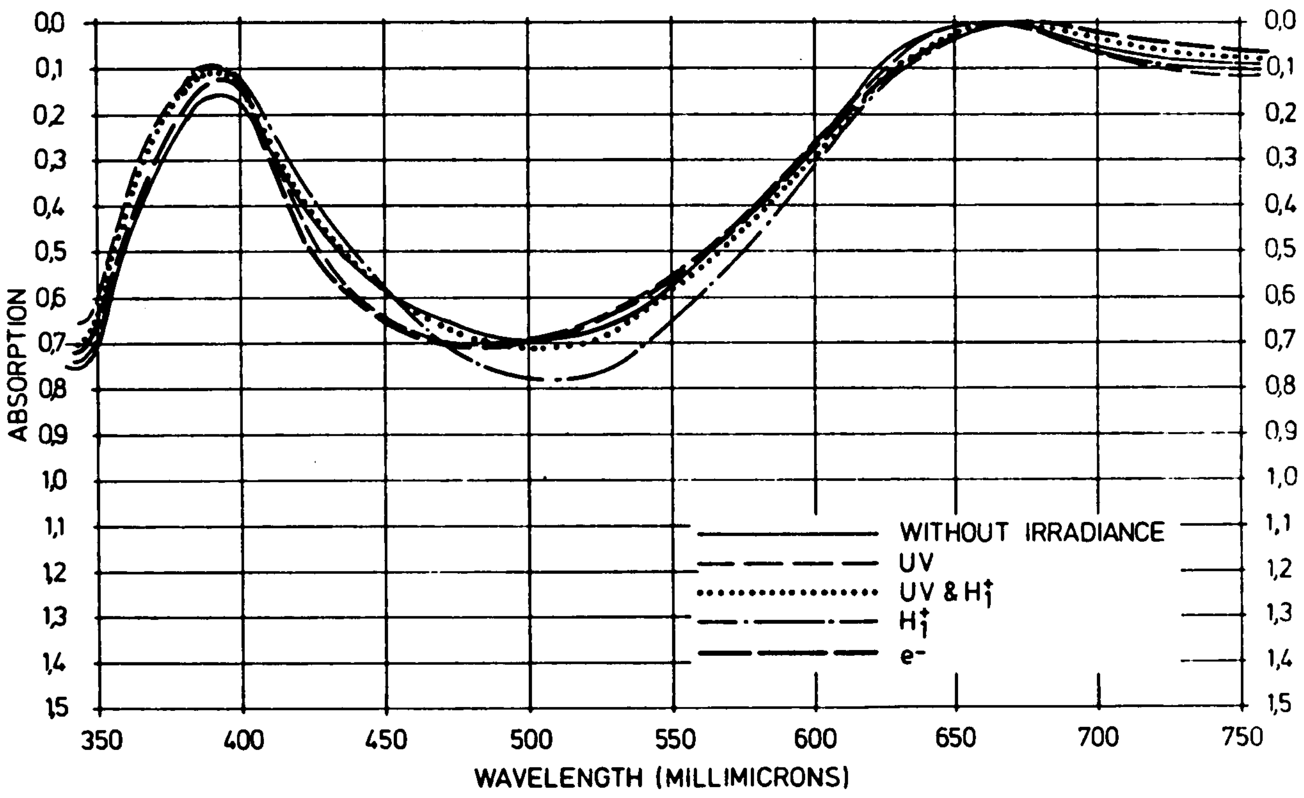

FIGURE 2 ABSORPTION OF A ZnS/Al_2O_3 INTERFERENCE FILTER BEFORE AND AFTER EXPOSURE TO UV, PROTONS, AND ELECTRONS. THIS IF-FILTER HAS NO REFLECTOR.

Teflon FEP SSM with In_2O_3 top layer and Ag reflector.

The CC was deposited on top of the IF filter by indium evaporation under about 10^{-4} Torr oxygen partial pressure. To improve its mechanical stability, 10 % SnO_2 simultaneously with the In_2O_3 was brought onto the sample.

For measurement of their square resistance, electric leads were glued with ECOBOND 57 C to the gold-electrodes, about 10 mm long, in 10 mm distance. For comparison, a total of four Suprasil samples with CC were added. On Teflon FEP the thickness of the CC was in the 100 Å range, on Suprasil it was about 700 Å thick.[11]

4.0 TEST RESULTS

4.1 α_s Performance of Protected SSM and OSR

Of all the IF filter materials investigated, ZnS, ThF_4, and Al_2O_3 showed considerable stability under simulated solar radiation. Seven layer IF filters, fabricated from these materials, performed well under prolonged exposure to UV, protons and electrons.[10] These IF filter efficiently protect the underlaying substrates against α_s increases within the stated times of test.

To ascertain, that these test results, gained under accelerated test conditions with 7,5 solar constants are true at lower radiation levels, the tests were repeated with 3,5 solar constants, and finally with 2 solar constants. The UV exposure always amounted to 3000 ESH (equivalent sun hours). The proton doses somewhat exceeded $10^{16}/cm^2$.

Proton energies ranged from 10 KeVolt to 30 KeVolt, with 10 KVolt application during the 7,5 solar constant exposure, and 30 KVolt in conjunction with 3,5 solar constant UV irradiation. To avoid discharge damages to Teflon FEP and to the reflector, during the final combined exposure the proton acceleration potential was maintained at 20 KVolt.

The proton radiation intensities were too high for continuous proton exposure. Therefore the protons were applied in intervals during the UV irradiation, until $10^{16}/cm^2$ were brought onto the samples. In Table I the α_s data of the investigated candidate IF-filter on Suprasil and on Teflon FEP are compiled. Samples with In_2O_3 top layer are not included in this comparison. However, they perform as well as the samples without conductive layer. -

Table I
Solar Absorption Coefficients of IF Filter Protected SSM and OSR Before and After Exposure to 3000 ESH UV and Protons. The underlined data were measured with Suprasil as substrate. For the other samples, the IF filter were deposited on 5 mil thick Teflon FEP. All samples had aluminum reflectors, 1500 Å thick.

The samples exposed to UV are identical to those exposed to UV + protons, provided they have been tested under the same solar radiation intensity.

Differences among the samples are the result of fabrication techniques, and the location of the IF filter reflection maximum, which was varied within the spectral range from 4600 Å to 5250 Å. During the course of this study these

RADIATION DOSES	IF-FILTER MATERIALS	ALPHA - S								
		2.0 SK			3.5 SK			7.5 SK		
		BEFORE	AFTER	$\Delta\alpha_s$ %	BEFORE	AFTER	$\Delta\alpha_s$ %	BEFORE	AFTER	$\Delta\alpha_s$ %
UV	ZnS / ThF_4	0.160	0.163	2	0.150	0.165	10	0.138	0.142	3
3000 ESH	ZnS / ThF_4	0.160	0.169	6	0.180	0.210	17	0.166	0.168	1
	ZnS / Al_2O_3	0.160	0.160	0	0.192	0.205	7	0.178	0.182	2
	ZnS / Al_2O_3	0.160	0.160	0	0.175	0.1	10	0.197	0.198	1
UV & PROTONS	ZnS / ThF_4	0.185	0.194	5	0.165	0.193	17	0.138	0.146	6
3000 ESH	ZnS / ThF_4	0.171	0.181	6	0.167	0.184	10	0.166	0.173	4
AND	ZnS / Al_2O_3	0.162	0.164	1	0.185	0.203	10	0.186	0.210*	13
10^{16} H_1^+/cm^2	ZnS / Al_2O_3	0.160	0.160	0	0.173	0.178	3	0.212	0.219	3

TABLE I SOLAR ABSORPTION COEFFICIENTS OF IF-FILTER PROTECTED SSM AND OSR BEFORE AND AFTER EXPOSURE TO 3000 ESH UV AND PROTONS ($10^{16}/cm^2$).

*REFLECTANCE DETERIORATION HERE IS THE MAIN CAUSE OF $\Delta\alpha s$.

fabrication techniques were improved. The IF filter tested during the two solar constant exposure represent the final design.

Samples that suffered discharge damages were omitted from further evaluation. In general, such samples showed steep increases of their α_s after such damage occurred. Damages were visually recognizable through light yellow coloration of Teflon FEP or as a fine discharge pattern in the Al-reflector (Lichtenberg figures).

The error of the α_s data reported here is within $\pm$ 3 %, due to instrumental limitations, and also in dependence of the DK-2A calibration.

The measured data, Table I, indicate, that α_s increases after completion of the exposure to 3000 ESH UV as well as to 3000 ESV UV + 10^{16} protons/cm^2 are small. Only three times the α_s exceeds 10 %. The 13 % increase after combined UV and proton exposure at 7,5 SK partially can be attributed to slight damage of its Al-reflector.

In particular, there is no α_s increase due to decreasing UV intensity. Therefore, from these accelerated test data the α_s performance of Teflon FEP SSM and Suprasil OSR with IF filter protection may be extrapolated to one solar constant exposure without underestimation of the consequences for satellite thermal household control.

4.2 Conductive Coating Resistance Performance

The resistances of the samples with conductive coating were repeatedly measured prior to and after evacuation of the test chamber. These measurements were continued during sample exposure to simulated solar radiation and encompassed all samples with conductive coatings within the vacuum chamber, also those, which were not yet irradiated.

Under vacuum the square resistance of the In_2O_3 layers soon increased. At the beginning these resistances were in the 3 K ohm range. Only the resistance of the In_2O_3 coats on Suprasil remained around 250 to 300 ohms.

After a few days under vacuum, without any radiation exposure, drastic increases of the resistance on all samples with Teflon FEP substrate were measured. The resistance varied between the samples from $10^8\ \Omega$ up to $10^{11}\ \Omega$, and remained within this range, with variations in the course of time under vacuum. After exposure to air, these resistances remained within above range. Only the conductive coatings on Suprasil maintained constant resistances.

Microscopic inspection of the top layers on all Teflon FEP samples revealed many fine cracks accross the sample surfaces. Such cracks frequently had parallel orientation, but often little isolated islands were found atop the substrate.

These fine cracks dont hurt the IF filter performance. Therefore they dont affect the SSM solar absorption coefficient. However, concerning the surface conductivity, these fine interruptions of the conductive path can lead to resistance increases of several orders of magnitude. Fortunately, charged particle currents even in a geosynchroneous orbit are low. For this reason surface resistances in the 10^8 ohm cm range are regarded to be tolerable.

For an efficient elimination of charges from thermal control surfaces it seems to be mandatory to ground connect conductive top layers all around to the satellite structure.

5.0 CONCLUSIONS

The results of this research program indicate, that it is possible to maintain within the error limits a constant solar absorption coefficient of IF filter protected SSM and OSR over an exposure time of 3000 ESH. Substrates were Teflon FEP and Suprasil. Extrapolation of these favorable results to other substrates may not be possible.

In conjunction with the thermal lay out of satellites, in general small increases of the thermal control surface solar absorption coefficient are tolerable. Therefore exposure times exceeding 3000 ESH are feasable.

Because of its radioactivity, ThF_4 was omitted from further consideration for fabrication of IF filter. Consequently, IF filter fabricated from alternating layers of ZnS and Al_2O_3 are the candidate design.

The IF filter under study are composed of seven layers. Five or three layer filter were not tested. - For improved IF filter stability a ZnS layer was placed on the outside, - because of its strong UV absorption below 3500 Å. Also, such eight layer IF filter with an Al_2O_3 $\lambda/4$ film a top showed no degradation of its spectral transmission after exposure to UV, UV+protons, protons, and electrons (UV at 3,5 SK) after 3000 ESH. ZnS alone may be sufficient as protective shield.[10]

The SSM and OSR α_s studies with exposures to three different UV radiation intensities lead to the conclusion, that for the IF filter tested solar radiation exposures up to 7,5 SK yield for constant ESH identical test results within the error limits, independent of the UV radiation intensity. Therefore, up to 7,5 SK α_s changes here are proportional to the number of ESH only.

All investigations were performed with samples 11 x 11 mm. Presently studies are under way to increase the sample size to dimensions interesting for the fabrication of satellite thermal control surfaces.

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